

University of Groningen

Intermanual transfer in prosthetic training

Romkema, Sietske

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version

Publisher's PDF, also known as Version of record

Publication date:

2016

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Romkema, S. (2016). *Intermanual transfer in prosthetic training*. [Thesis fully internal (DIV), University of Groningen]. Rijksuniversiteit Groningen.

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Intermanual Transfer Effect in Young Children After Training in a Complex Skill: Mechanistic, Pseudorandomized, Pretest-Posttest Study

Sietske Romkema, Raoul M. Bongers, Corry K. van der Sluis

S. Romkema, MSc, Department of Rehabilitation Medicine, University of Groningen, University Medical Center Groningen, CB40, Hanzeplein 1, 9700 RB, Groningen, the Netherlands. Address all correspondence to Ms Romkema at: s.romkema@umcg.nl.

R.M. Bongers, PhD, MSc, Center of Human Movement Sciences, University of Groningen, University Medical Center Groningen.

C.K. van der Sluis, MD, PhD, Department of Rehabilitation Medicine, University of Groningen, University Medical Center Groningen.

[Romkema S, Bongers RM, van der Sluis CK. Intermanual transfer effect in young children after training in a complex skill: mechanistic, pseudorandomized, pretest-posttest study. *Phys Ther*. 2015; 95:730–739.]

© 2015 American Physical Therapy Association

Published Ahead of Print:
December 11, 2014

Accepted: November 23, 2014
Submitted: October 16, 2013

Background. Intermanual transfer implies that motor skills learned on one side of the body transfer to the untrained side. This effect was previously noted in adults practicing with a prosthesis simulator.

Objective. The study objective was to determine whether intermanual transfer is present in children practicing prosthetic handling.

Design. A mechanistic, pseudorandomized, pretest-posttest design was used.

Setting. The study was conducted in a primary school in the Netherlands.

Participants. The participants were children who were able-bodied (N=48; 25 boys, 23 girls; mean age=5.1 years) and randomly assigned to an experimental group or a control group.

Intervention. The experimental group performed 5 training sessions using a prosthesis simulator on the training arm. Before (pretest), immediately after (posttest), and 6 days after (retention test) the training program, their ability to handle the prosthesis with the contralateral (test) arm was measured. The control group only performed the tests. Half of the children performed the tests with the dominant hand, and the other half performed the tests with the nondominant hand.

Measurements. During the tests, movement time and control of force were measured.

Results. An interaction effect of group by test was found for movement time. Post hoc tests revealed significant improvement in the experimental group between the posttest and the retention test. No force control effect was found.

Limitations. Only children who were able-bodied were included. Measurements should have been masked and obtained without tester interference. The fact that 4 children whose results were slower than the mean result discontinued training may have biased the findings.

Conclusions. The intermanual transfer effect was present in 5-year-old children undergoing training in prosthetic handling. After training of one hand, children's movement times for the other, untrained hand improved. This finding may be helpful for training children who are novice users of a prosthesis.



Post a Rapid Response to
this article at:
ptjournal.apta.org

The finding that a novel motor task trained on one side of the body leads to an improvement in the performance of that task on the other side is called *intermanual transfer*.¹⁻³ The intermanual transfer effect can be useful in rehabilitation. This effect was previously shown for prosthetic training in adults.^{4,5} When prosthetic training is started within 1 month after amputation, prosthetic handling and acceptance will be improved.⁶ However, after an upper limb amputation, it often is not feasible to obtain a prosthesis within 1 month. To enable the patient to start training during this period, the unaffected arm can be used. Training the prosthetic skills of the unaffected arm can improve the skills of the affected arm. To date, it is not known whether the intermanual transfer effect can be applied in the rehabilitation of children learning to use a prosthesis. Intermanual transfer was previously found to be present from the age of 5 years,⁷⁻⁹ with improvement continuing until at least 17 years of age.⁸⁻¹²

In studies with young children (4-6 years old), the intermanual transfer effect was shown for simple tasks, such as button-press tasks,⁷ matching,^{8,9} or finger lifting.¹³ However, the successful use of intermanual transfer in a rehabilitation setting would require more than just simple tasks. Rehabilitation requires complex tasks,¹⁴ which contain more degrees of freedom and multiple task aspects and which involve real-world activities.¹⁵ Such tasks are especially useful when clinically relevant. Therefore, in this study, functional prosthetic training was used to test the intermanual transfer of a complex and novel task in young children.

All previous intermanual transfer studies with children comprised a 1-day training program.^{7-10,12,13,16,17} However, in a regular training pro-

gram, learning to execute a complex task, such as handling a prosthesis simulator, takes longer than a single day. Improvement in movement time while practicing prosthetic handling can be seen after at least 5 days,^{18,19} and it takes even longer to learn to control generated force.¹⁹ In adults, intermanual transfer of movement time was found in a retention test performed 6 days after prosthetic training.⁵ Retention effects have been reported in the literature and are assumed to be due to the consolidation of motor memory.²⁰ We tested movement time and force control in children by using intermanual transfer immediately after several days of training and later in a retention test.

For rehabilitation, the intermanual transfer effect needs to be symmetrical, meaning that the effect is transferred from the nondominant side to the dominant side and vice versa because, obviously, both sides can be affected. The literature on the direction of transfer provides various conclusions. In studies on intermanual transfer in children, asymmetry in laterality was often found.^{10,13,16,17} It seemed that more complex and novel tasks mostly showed asymmetry,^{16,21,22} whereas in adults who used a prosthesis simulator, symmetry was found.^{5,23} Therefore, in the present study, we aimed to determine the direction of transfer in children by using a prosthesis simulator.

The objective of this study was to reveal the intermanual transfer effect on 1 arm after training of the contralateral arm with a prosthesis simulator in 5-year-old children. We compared the movement time of a training group with that of a control group (no training), and we tested the difference in intermanual transfer between the dominant hand and the nondominant hand. In addition, we compared the control of force of

an experimental group with that of a control group.

Method

Design Overview

Participants in the experimental group started with a pretest (first day) to establish the baseline skills of the “affected” arm with the simulator and then practiced with the opposite, “unaffected” arm (day 1 until day 4 or 5) (see below). Subsequently, the participants performed a posttest (last day of training) and a retention test (6 days later) of the affected arm with the simulator. Participants in the control group executed the pretest, posttest, and retention test of only the affected arm on the same test days but without receiving any training (Fig. 1). Because of practical limitations, the training program consisted of 4 sessions for half of the children and 5 sessions for the other half (both experimental and control groups). Sessions took place on consecutive days at about the same time every day. The flow of the participants in the study is shown in the CONSORT diagram presented in Figure 2.

Setting and Participants

Fifty-two children participated. Three girls and 1 boy from the experimental group were excluded because of a lack of motivation. Three of these children trained for 3 days, 1 trained for 4 days, and all of them dropped out before the posttest. The 48 children (25 boys, 23 girls; mean age=5.1 years, range=4-6) who were included were right-



Available With
This Article at
ptjournal.apta.org

- **eFigure:** Deformable Object
- **eTable:** Means for Deformation of Objects in the Force Control Task Per Test

handed, were able-bodied, were free of neurological and upper extremity musculoskeletal problems, had normal or corrected-to-normal sight, and had no earlier experience with the prosthesis simulator. The children were recruited at their primary school. Parents signed an informed consent form for participation of their child. The training procedures and the consent form were approved by the national medical ethics committee (NL37362.000.11).

A myoelectric prosthesis simulator (OIM Orthopedie, Haren, the Netherlands) (Fig. 3),^{5,24} adapted for children, was used in the experiments. The simulator was controlled in the same way as a real myoelectric prosthesis but could be attached to an unaffected arm. The simulator consisted of a myoelectric hand, the Electrohand 2000 (Otto Bock Healthcare Products GmbH, Vienna, Austria), which was attached to an open cast in which the hand was placed. The cast extended into a splint along the forearm and was adjustable in length. The splint could be attached to the arm with a self-adhesive Velcro (Velcro USA Inc, Manchester, New Hampshire) sleeve. The hand was controlled by electrical activity derived from muscle contractions, detected by 2 electrodes that were placed on the muscle bellies of the wrist flexor and extensor muscles. The prosthetic hand had proportional speed control (15–399 mm/s) and proportional grip force control (0 to ± 35 N).

For the training sessions, the Southampton Hand Assessment Procedure (SHAP)²⁵ was used; this test evaluates the functionality of prostheses while different grasps are performed. The test consists of 26 tasks: 12 abstract tasks and 14 tasks from daily life. The SHAP was chosen because it standardized the training. Some of the tasks were not feasible because of the smaller hand opening

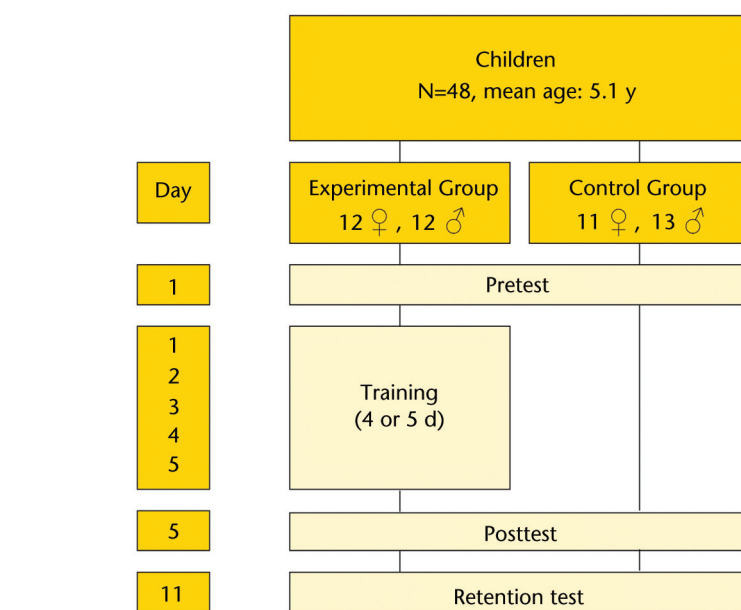


Figure 1.
Design of the study.

and reduced power of the prosthetic hand and, therefore, required adaptation (Appendix).

For registration of the movement times (in milliseconds) for the test tasks, E-Prime, an application suite (Psychology Software Distribution, Stittenham, York, United Kingdom) was used. With this suite, the tasks were shown on a screen, and the accompanying times were saved.

Two deformable objects (eFigure, available at ptjournal.apta.org) were used to measure force control during the tests. The deformable objects consisted of 2 plates ($4 \times 3.5 \times 9$ cm) with a spring in between them; one object had a spring that was stiffer than the spring in the other object.

Randomization and Interventions

The children were pseudorandomly assigned to the experimental group or the control group. Boys and girls were equally divided into these groups. For the measurement of lat-

erality, the test side (dominant versus nondominant) was equally represented in the groups. All test tasks were executed in an order that was randomized with E-Prime.

All test and training sessions took place in the primary school and were performed individually in a quiet room. The testers were trained in a pilot study to execute the measurements according to a protocol. For most testing sessions, 2 testers were present to make sure testing was done the same way. A session always started with a standard procedure to fit the simulator. The electrodes were placed on the wrist extensor and flexor muscles, which had been marked with a permanent marker after palpation. The sensitivity of the electrodes was always highest when starting. If the child could not easily open and close the prosthesis—for example, because of the 2 electrodes counteracting—the sensitivity was adapted. The maximum speed of the hand was set to the default setting of 6 (on a scale of 1–6). After fitting of the stimulator, verbal instruction for

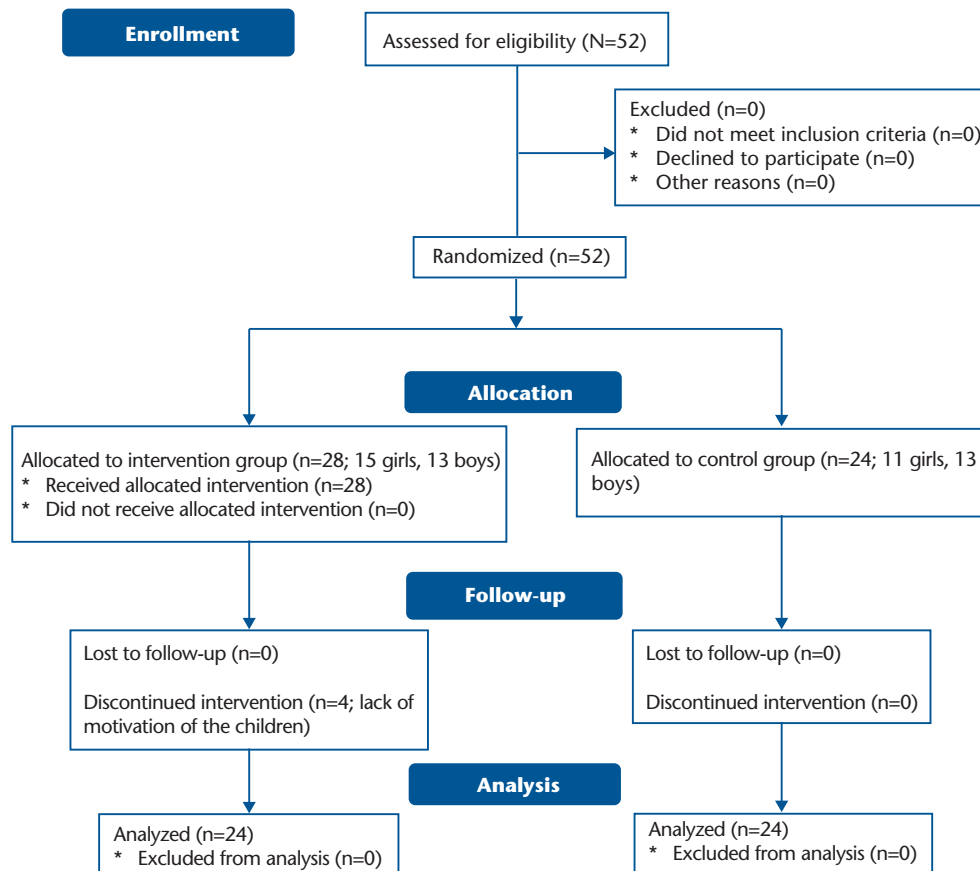


Figure 2.
Diagram of the flow of participants in the study.

task execution was given with the request to perform all of the tasks as rapidly and accurately as possible.

Pretest, posttest, and retention test. During all tests, participants sat, with the elbow flexed 90 degrees,

at a table on which the starting and ending positions of the objects were marked. Three functional tasks and 2 force control tasks were all executed 3 times. The functional tasks were based on the 3 different ways in which a prosthesis is used in daily life²⁶: direct

grasping, indirect grasping, and fixating. The 3 functional tasks (as used in the adult study⁵) were as follows: the mug task, in which a mug had to be picked up and put on a 25-cm-high shelf (direct grasping); the jar lid task, in which a jar had to be handed from the sound (training) hand to the prosthetic hand, after which the lid had to be removed with the sound hand (indirect grasping); and the pen case task, in which a pen case was fixed with the prosthetic hand while the sound (training) hand opened and closed the zipper (fixating).

To measure movement times with E-Prime, the researcher released the space bar when the child started to open the prosthetic hand and then pressed the space bar after task com-

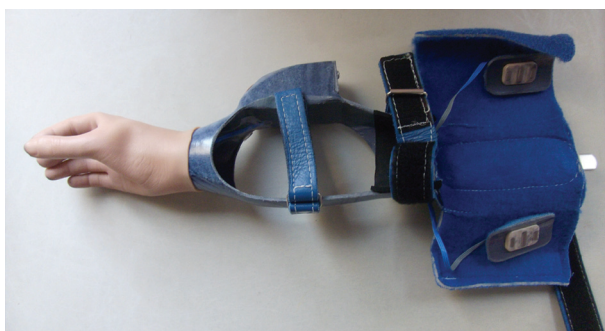


Figure 3.
Prosthesis simulator for children.

pletion. Movement times were measured in milliseconds.

In the force control tasks, 2 deformable objects⁵ had to be picked up and put on a shelf 25 cm above the table, with the instruction to compress the objects as little as possible. The maximum deformation was measured by reading a scale attached to the plates.

The 2 dependent variables, movement time and force control, were used for the analysis.

Training sessions. During all training sessions, the children in the experimental group executed tasks from the SHAP.²⁵ On the first and last days, only half of the SHAP tasks were performed together with the tests, whereas on the other training days, the complete SHAP was performed once. This approach was used to keep the children focused and motivated. At the end of each session, children could color a drawing to motivate them to participate in the next session. After completion of the experiment, all children received a toy.

Data Analysis

The means of the movement times and the means of the deviation in the force control tasks for the 3 trials in each test were calculated with the IBM Social Package Statistical Science (SPSS) 19.0 software package (IBM Corp, Armonk, New York). For comparison of the movement times and the object deformations in the different tasks for the 2 groups, *z* scores were used; *z* scores were calculated per task and were used for all further analyses.

Baseline. The results on the pretests for the experimental and control groups were compared with a repeated-measures analysis of variance (ANOVA) to assess baseline differences. For the movement

times, the task (mug, jar lid, and pen case) was a within-subject factor, and the training group (training and control) was a between-subjects factor. For the deviation in force control, the task (strong and light springs) was a within-subject factor, and the training group (training and control) was a between-subjects factor.

Movement time and laterality.

A repeated-measures ANOVA on the movement time was conducted for the functional tasks with the test (pretest, posttest, and retention test) and the task (mug, jar lid, and pen case) as within-subject factors and the training group (training and control) and test arm (dominant and nondominant) as between-subject factors.

Training days. Because the training took place for 4 or 5 days, we assessed whether the duration of training influenced the data. In an additional analysis, the number of training days was entered as a between-subjects factor in the repeated-measures ANOVA on the movement time.

Force control tasks. Another repeated-measures ANOVA was conducted for the maximum deformation in the force control tests with the test (pretest, posttest, and retention test) and the task (strong and light springs) as within-subject factors and the training group (training and control) as a between-subjects factor.

Dropouts. An additional analysis was performed on the data from the children who dropped out. The mean movement times and mean object deformations on the pretest were compared with the 95% confidence interval of the mean scores for all children.

When sphericity was violated, the degrees of freedom were adjusted with the Greenhouse-Geisser correction. An alpha value of .05 was used. Bonferroni corrections were used in the post hoc tests.

Role of the Funding Source

This study was supported by grants 60-62300-98-119 from ZonMW, 1103-029 from Fonds NutsOhra, R2011147 from Revalidatiefonds, 210.130 from Stichting Beatrixoord, and 1103 from OIM Stichting. None of the funding agencies had any influence on the design and conduct of the study; on the collection, management, analysis, and interpretation of the data; or on the preparation, review, or approval of the article.

Results

Baseline

No baseline differences between the experimental group and the control group were found for movement time or force control.

Movement Time

The ANOVA on the *z* scores of the movement time for the 3 functional tasks revealed a significant difference in the interaction between group and test ($F_{2,88}=3.215$, $P=.045$) (Table). Two paired *t* tests revealed that the experimental group showed improvement from the posttest to the retention test ($t_{23}=2.54$, $P=.018$) but that the control group did not (Fig. 4). A significant difference was found between tests ($F_{2,88}=83.390$, $P=.000$). Post hoc tests revealed that the pretest differed significantly from the posttest and from the retention test (P values of $<.001$), indicating improvement after training.

Laterality

No interaction effect between hand dominance and test was found in the movement times, revealing no laterality effects. An interaction effect between task and hand dominance

Table.

Means (95% Confidence Intervals) for Movement Times (in Seconds) in Functional Tasks Per Test

Test	Training Group			Control Group		
	Mug	Pen Case	Jar Lid	Mug	Pen Case	Jar Lid
Pretest	9.17 (7.65, 10.69)	8.30 (6.90, 9.70)	15.52 (13.62, 17.41)	8.46 (6.93, 9.98)	7.81 (6.40, 9.22)	14.50 (12.59, 16.41)
Posttest	5.67 (4.85, 6.50)	5.81 (4.68, 6.95)	9.69 (8.58, 10.81)	6.22 (5.39, 7.05)	5.68 (4.54, 6.82)	8.51 (7.39, 9.62)
Retention test	5.03 (4.07, 6.00)	5.13 (4.24, 6.03)	8.16 (6.50, 9.82)	6.73 (5.77, 7.70)	4.81 (3.91, 5.71)	9.73 (8.06, 11.40)

was found ($F_{2,88}=3.394$, $P=.038$). Post hoc tests revealed a significant difference between hands in the jar lid task ($t_{46}=-3.409$, $P=.001$). Although the mug and pen case tasks were performed at about the same speeds regardless of the test arm, the jar lid task was executed faster when the nondominant test hand held the jar and the dominant hand opened the lid (Fig. 5).

Training Days

No difference was found between the group that trained for 4 consecutive days and the group that trained for 5 consecutive days.

Force Control Tasks

The ANOVA on the z scores of the object deviation indicated no significant main or interaction effect, implying no difference between the groups (eTable, available at ptjournal.apta.org).

Dropouts

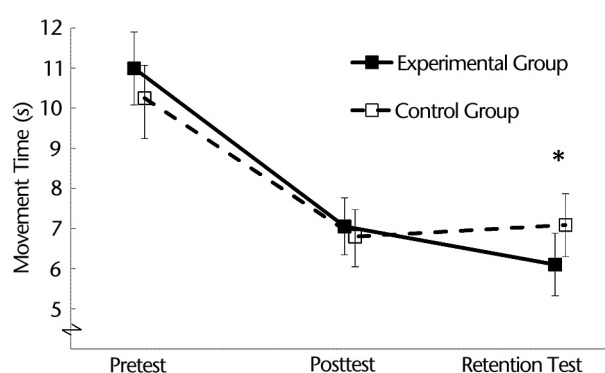
The movement times of the children who dropped out were between 11.5 and 15.4 seconds on the pretest; the upper bound of the 95% confidence interval of the children who were included was 11.3 seconds. The upper bounds of the 95% confidence intervals for the deformations of light and heavy objects were 9.1 and 6.3 mm, respectively. For both objects, 3 of the 4 excluded children scored worse (between 7.9 and 10.1 mm for the light object and between 5.2 and 7.7 mm for the heavy object).

Discussion

An intermanual transfer effect was found after training on prosthetic handling in young children. After training of one side, the movement time of the contralateral side improved significantly on a retention test relative to the findings for the control group. To our knowledge, this is the first report of improvement in the execution of a more complex and novel task through intermanual transfer in 5-year-old children.

Our design was innovative in several respects. Contrary to other studies involving young children, the present study involved complex tasks. Instead of tasks such as finger lifting¹³ or button pressing,⁷ our participants had to practice activities of daily living while wearing a prosthesis simulator. Such complex tasks might be more difficult to learn; thus, a small intermanual transfer

effect might be expected. On the other hand, the tasks were novel, implying a larger learning effect at the start of the training exercise—which would foster an intermanual transfer effect. Furthermore, to promote motor memory consolidation, we conducted the training exercise over several days,²⁰ whereas other studies usually included training for one, sometimes brief, session.^{7–10,12,13,16,17} Thus, the possible small transfer effect caused by task complexity might be balanced through the use of novel tasks and more training days. Neither a complex and novel task nor a longer training period was used in previous studies with young children; hence, the relevance of the effects and their possible interactions warrant further study to advance the understanding of intermanual transfer in young children.


Figure 4.

Means (95% confidence intervals) for movement times (in seconds) in all functional tasks for the 3 tests administered to the experimental and control groups. Real movement times are shown, but analyses were performed on z scores. * $P<.025$.

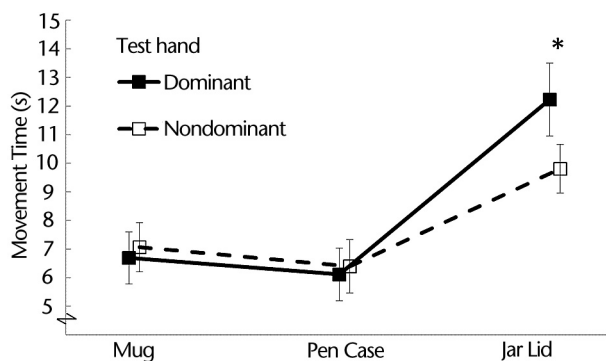


Figure 5.

Means (95% confidence intervals) for movement times (in seconds) in 3 functional tasks for dominant and nondominant test hands. Real movement times are shown, but analyses were performed on z scores. * $P < .025$.

The difference in movement times between the training groups was found on the retention test. Improvement between the posttest and the retention test has been described more often in the literature.²⁰ Interestingly, the retention test was found to be a better indicator for learning. This learning effect was probably due to the consolidation of memory.²⁰ Therefore, it can be assumed that the results on the retention test for the training group revealed a learning effect that was retained.

The direction of the intermanual transfer of movement time for the complex tasks was symmetrical. This means that the transfer of the effect from the dominant side to the nondominant side did not differ from that in the opposite direction. Studies of adults training with a prosthetic simulator showed similar symmetrical effects.^{5,23} Other studies, however, revealed mostly asymmetry of transfer for complex and novel tasks.^{16,21,22,27} A possible explanation for the symmetry in both the present study with children and our previous study with adults⁵ is that 2 of the 3 functional test tasks were executed bimanually. The effect for the test hand might have been limited by the use of 2 hands. However, Weeks et al²³ used only unilateral

tasks and still found symmetrical effects. Studies with children, all using unilateral tasks, showed asymmetrical effects, although not always in the same direction. Some studies showed larger effects from the nondominant side to the dominant side,^{13,17} but some studies showed effects in the other direction.^{10,16} In a recent study, Pan and van Gemmert²⁸ demonstrated differences in the symmetry of transfer with different performance parameters. For instance, movement time transferred symmetrically, whereas initial movement direction in a point-to-point drawing task did not. However, the findings of Pan and van Gemmert²⁸ cannot explain all of the findings regarding symmetry in intermanual transfer. There appear to be more subtleties to laterality in intermanual transfer, and this topic warrants further study.

To increase sample size, we performed experiments at 2 schools. At one school, a training program of only 4 (instead of 5) consecutive days was feasible. An additional statistical analysis showed no difference in performance for groups of children with different numbers of training days. We hope that bias due to this difference was minimal. Furthermore, 4 children did not com-

plete the study. The mean movement times of these children on the pretest were slower, and the means of the maximum deformation of the compressible objects were usually higher for these children than for the other study participants. Perhaps prosthetic use was more difficult for these children, causing them to drop out. This factor might have biased our results, thus limiting their applicability.

No intermanual transfer effect for force control was found in the experimental group. Although the transfer of force control is possible,^{29,30} learning to control force with a prosthesis is difficult and takes time.^{31,32} The training program consisting of SHAP tasks did not focus on force control in particular. Furthermore, in adults who received SHAP training, the transfer of force control also was not found.⁵ Presumably, to obtain intermanual transfer of force control, specific attention to force control in the training exercise or a longer training program may be necessary.

The effect of intermanual transfer improves with age⁸⁻¹²; that is, intermanual transfer in simple tasks is observed from the age of 5 years,⁷⁻⁹ and the effect increases until at least the age of 17 years.¹⁰ Parlow and Kinsbourne¹⁶ used an inverted writing task for groups of adults and children and found similar intermanual transfer effects in both groups. When we compared our results for children with those for adults,⁵ the patterns in the transfer of the movement times also were similar; that is, the largest differences between the experimental group and the control group were found on the retention test, revealing a motor memory consolidation effect.²⁰ However, the differences and similarities for the intermanual transfer effects in the different age groups should be interpreted with caution because of the

differences in training. Children executed the adapted SHAP 4 times, whereas adults executed the original SHAP 8 times. Therefore, determining whether there is an improvement with age in the intermanual transfer of learning with a prosthesis simulator is difficult.

The present study was designed to imitate a clinical setting. Improvement in the execution of a clinically relevant skill—namely, prosthetic handling—was measured. We used complex and novel tasks, extended the training program to several days, and used activities of daily living to train the participants. Moreover, test tasks and training tasks differed, implying that we measured the learning of a skill instead of improvement in the execution of a learned task. An interesting consequence, in terms of the generalizability of our findings and the mimicking of a clinical setting, is that our findings might be applicable to the rehabilitation of children with upper limb amputation. Through intermanual transfer, children can start training directly with the unaffected arm after an amputation. Handling of objects while using a prosthesis, even at a starting level, along with acceptance of the prosthesis could improve.⁶

Now that the concept of intermanual transfer after the execution of a complex task has been shown to be present in children who are able-bodied, it is important to establish whether such an effect also can be found in children with peripheral upper limb disorders affecting one side of the body, such as reduction deficiency or brachial plexus injury. The use of intermanual transfer in children with a disorder on one side of the body has not been studied. Therefore, it might be interesting to explore whether the intermanual transfer concept is applicable to different groups of patients. Future research should include children with an

upper limb amputation as well as find a way to overcome the limitations of the design of the present study. In addition, this concept should be applied to older children.

A limitation of the present study is that, to generalize the effect of intermanual transfer, we should have obtained measurements in novice users of a prosthesis. However, because of the low incidence of amputations, we had to rely on children who were able-bodied by using a prosthesis simulator. We assume that a comparable intermanual transfer effect can be found in children who are novice users of a prosthesis because they are usually healthy and because the kinematic performances of adults using prostheses or prosthesis simulators showed relevant similarities.³¹

A further limitation of the present study is that the testers administered the training program as well as the tests; as a result, the testing was not masked. Furthermore, because of the children's limited focus, movement times were recorded by a researcher instead of by the children. The researcher pressing the button may have introduced bias. However, this procedure was used because—in an unpublished pilot study—the children often forgot to press the button; this situation would have led to even greater bias. Nevertheless, this limitation should be considered in the interpretation of the data. In subsequent experiments, movement times should be assessed with kinematic measurements. Finally, the test-retest properties of the test tasks were unknown. The tests used were chosen because they represented several skills found in tasks of daily living and could be administered in a short span of time.

In conclusion, an intermanual transfer effect was found following a prosthetic training program in children.

To our knowledge, we are the first to find an intermanual transfer effect in young children performing complex and novel skills. Using a situation resembling a clinical setting, we found a movement time effect that might be applicable to prosthetic training.

All authors provided concept/idea/research design, writing, data analysis, project management, and fund procurement. Ms Romkema provided data collection and participants. Dr Bongers and Dr van der Sluis provided facilities/equipment, institutional liaisons, and consultation (including review of manuscript before submission). The authors acknowledge Juliët Visser, Charissa Jessurun, and Ecaterina Vasluian for assistance with collecting data. They also thank Johan Horst and Theo Schaaphok for technical assistance with the simulator and Emyl Smid for assistance with preparing the experimental equipment.

The treatment of the participants in this study was in accordance with the National Medical Ethics Committee (NL37362.000.11).

This study was supported by grants 60-62300-98-119 from ZonMW, 1103-029 from Fonds NutsOhra, R2011147 from Revalidatiefonds, 210.130 from Stichting Beatrixoord, and 1103 from OIM Stichting.

Nederlands Trial Register (NTR) registry number: NTR3053.

DOI: 10.2522/ptj.20130490

References

- 1 Hicks RE, Gualtieri CT, Schoeder SR. Cognitive and motor components of bilateral transfer. *Am J Psychol*. 1983;96:223–228.
- 2 Karni A, Meyer G, Rey-Hipolito C, et al. The acquisition of skilled motor performance: fast and slow experience-driven changes in primary motor cortex. *Proc Natl Acad Sci U S A*. 1998;95:861–868.
- 3 Kumar S, Mandal MK. Bilateral transfer of skill in left- and right-handers. *Laterality*. 2005;10:337–344.
- 4 Weeks DL, Anderson DI, Wallace SA. The role of variability in practice structure when learning to use an upper-extremity prosthesis. *J Prosthet Orthot*. 2003;15:84–88.
- 5 Romkema S, Bongers RM, van der Sluis CK. Intermanual transfer in training with an upper-limb myoelectric prosthesis simulator: a mechanistic, randomized, pretest-posttest study. *Phys Ther*. 2013;93:22–31.

- 6 Malone JM, Fleming LL, Roberson J, et al. Immediate, early, and late postsurgical management of upper-limb amputation. *J Rehabil Res Dev*. 1984;21:33-41.
- 7 Uehara I. No transfer of visuomotor learning of button-pressing from right to left hands in right-handed four-year-olds. *Percept Mot Skills*. 1998;87:1427-1440.
- 8 Benoit-Dubrocard S, Touche ME. Letters as spatial-oriented shapes and/or graphemic signs: a developmental study of left- and right-handed girls during the period of learning to read. *Brain Lang*. 1993;44:385-399.
- 9 O'Leary DS. A developmental study of interhemispheric transfer in children aged five to ten. *Child Dev*. 1980;51:743-750.
- 10 Byrd R, Gibson M, Gleason MH. Bilateral transfer across ages 7 to 17 years. *Percept Mot Skills*. 1986;62:87-90.
- 11 Brizzolara D, Ferretti G, Brovedani P, et al. Is interhemispheric transfer time related to age? A developmental study. *Behav Brain Res*. 1994;64:179-184.
- 12 Chicoine AJ, Proteau L, Lassonde M. Absence of interhemispheric transfer of unilateral visuomotor learning in young children and individuals with agenesis of the corpus callosum. *Dev Neuropsychol*. 2000;18:73-94.
- 13 Edwards JM, Elliott D. Asymmetries in intermanual transfer of training and motor overflow in adults with Down's syndrome and nonhandicapped children. *J Clin Exp Neuropsychol*. 1989;11:959-966.
- 14 Oujamaa L, Relave I, Froger J, et al. Rehabilitation of arm function after stroke: literature review. *Ann Phys Rehabil Med*. 2009;52:269-293.
- 15 Wulf G, Shea CH. Principles derived from the study of simple skills do not generalize to complex skill learning. *Psychon Bull Rev*. 2002;9:185-211.
- 16 Parlow SE, Kinsbourne M. Asymmetrical transfer of training between hands: implications for interhemispheric communication in normal brain. *Brain Cogn*. 1989;11:98-113.
- 17 Senff O, Weigelt M. Sequential effects after practice with the dominant and non-dominant hand on the acquisition of a sliding task in schoolchildren. *Laterality*. 2011;16:227-239.
- 18 Vasluian E, Bongers RM, Reinders-Messelink HA, et al. Learning effects of repetitive administrations of Southampton Hand Assessment Procedure in novice prosthetic users. *Arch Phys Med Rehabil*. 2014;46:788-797.
- 19 Bouwsema H, van der Sluis CK, Bongers RM. Changes in performance over time while learning to use a myoelectric prosthesis. *J Neuroeng Rehabil*. 2014;11:16.
- 20 Kantak SS, Winstein CJ. Learning-performance distinction and memory processes for motor skills: a focused review and perspective. *Behav Brain Res*. 2012;228:219-231.
- 21 Morris T, Newby NA, Wininger M, Craelius W. Inter-limb transfer of learned ankle movements. *Exp Brain Res*. 2009;192:33-42.
- 22 Parker-Taillon D, Kerr R. Manual asymmetries within the performance of a complex motor task. *Hum Mov Sci*. 1989;8:33-44.
- 23 Weeks DL, Wallace SA, Anderson DI. Training with an upper-limb prosthetic simulator to enhance transfer of skill across limbs. *Arch Phys Med Rehabil*. 2003;84:437-443.
- 24 Bouwsema H, van der Sluis CK, Bongers RM. The role of order of practice in learning to handle an upper-limb prosthesis. *Arch Phys Med Rehabil*. 2008;89:1759-1764.
- 25 Light CM, Chappell PH, Kyberd PJ. Establishing a standardized clinical assessment tool of pathologic and prosthetic hand function: normative data, reliability, and validity. *Arch Phys Med Rehabil*. 2002;83:776-783.
- 26 van Lunteren A, van Lunteren-Gerritsen GH, Stassen HG, Zuihoff MJ. A field evaluation of arm prostheses for unilateral amputees. *Prosthet Orthot Int*. 1983;7:141-151.
- 27 Teixeira LA. Timing and force components in bilateral transfer of learning. *Brain Cogn*. 2000;44:455-469.
- 28 Pan Z, van Gemmert AW. The direction of bilateral transfer depends on the performance parameter. *Hum Mov Sci*. 2013;32:1070-1081.
- 29 Chang EC, Flanagan JR, Goodale MA. The intermanual transfer of anticipatory force control in precision grip lifting is not influenced by the perception of weight. *Exp Brain Res*. 2008;185:319-329.
- 30 Bensmail D, Sarfeld AS, Fink GR, Nowak DA. Intermanual transfer of sensorimotor memory for grip force when lifting objects: the role of wrist angulation. *Clin Neurophysiol*. 2010;121:402-407.
- 31 Bouwsema H, Kyberd PJ, Hill W, et al. Determining skill level in myoelectric prosthesis use with multiple outcome measures. *J Rehabil Res Dev*. 2012;49:1331-1348.
- 32 Smurr LM, Gulick K, Yancosek K, Ganz O. Managing the upper extremity amputee: a protocol for success. *J Hand Ther*. 2008;21:160-176.

Intermanual Transfer Effect in Young Children After Training in a Complex Skill

Appendix.

Modifications of Southampton Hand Assessment Procedure (SHAP) Tasks^a

Task	Objects and Protocol	Downsized Object	Modified Protocol
Abstract object tasks			
Light sphere	Wooden sphere transferred from location 1 to location 2	Sphere (diameter=3 cm)	—
Light power	Wooden cylinder transferred from location 1 to location 2	Cylinder (height=10 cm, diameter=3 cm)	—
Light lateral	Wooden shape in the form of a squared mug transferred from location 1 to location 2	—	The object was positioned with the handle lateral to the side on which the participant was wearing the simulator, not facing the participant
Heavy sphere	Metal sphere transferred from location 1 to location 2	Sphere (diameter=3 cm)	—
Heavy power	Metal cylinder transferred from location 1 to location 2	Cylinder (height=10 cm, diameter=3 cm)	—
Heavy lateral	Metal shape in the form of a squared mug transferred from location 1 to location 2	—	The object was positioned with the handle lateral to the side on which the participant was wearing the simulator, not facing the participant
Activities of daily living tasks			
Pick up coins	Independently pick up 4 coins and place them in a jar	—	The coins were dragged to the edge of the table by the participant, the assessor held a coin with his or her index finger at the edge of the table, and the participant picked up the coin and placed it in a tin
Cut food	Cut a plastic block with a knife	—	The assessor helped fix the knife in the prosthetic hand
Remove a jar lid	Pick up a jar with the nonassessed hand; open the lid with the assessed hand using a flexion grip with the lid in the palm	Smaller jam jar (diameter=4 cm, diameter of lid=4.2 cm, height=9 cm)	—
Pour water from a jug	Place a jug containing 100 mL of water with the handle oriented to the side of the assessed hand, lift it up by the handle, and pour the water into a jar	50 mL of water	—
Pour water from a carton	Fill a carton with 200 mL of water, grasp it, and pour the water into a jar	Smaller juice carton with 100 mL of water (length=5.1 cm, width=3.7 cm, height=11 cm)	—
Move a full jar	Lift a full jar of water from location 1, pass it over a barrier (a carton), and place it at location 2 (location 1 for the jar is the side opposite the assessed hand)	Smaller jam jar with 150 mL of water (diameter=3.7 cm, height=10.1 cm)	—
Move an empty tin	Lift an empty tin from location 1, pass it over a barrier (a carton), and place it at location 2 (location 1 for the jar is the side opposite the assessed hand)	Smaller tin (diameter=3.5 cm, height=9 cm)	—
Move a tray	Using both hands and remaining seated, pick up a tray from location 1, pass it over a barrier, and place it at location 2 (the tray is placed on the side opposite the assessed hand, and the SHAP unit is placed with the longer side facing the participant to serve as a barrier)	Smaller, lighter tray (length=42 cm, width=26 cm)	The unit was placed with the shorter side facing the participant
Open and close a zipper	Open and close a zipper	Extension of the pull tab of the zipper (paper clip)	The assessor held the pull tab for easier grasping
Rotate a screw 90°	Guide a screwdriver to a screw (the screwdriver is placed on a form-board on the side of the assessed hand, and the screw is clipped on the exterior of the SHAP unit on the side of the assessed hand; both hands can be used to guide the screwdriver to the screw, but only the assessed hand can turn the screwdriver)	—	The participant picked up the screwdriver with the nonassessed hand and passed it to the assessed hand, and the assessor helped fix the screwdriver in the prosthetic hand

^a —=no modification was applied. Location 1 and location 2 were specified on the form-board for each task. Adapted and reprinted with permission from: Vasluian E, Bongers RM, Reinders-Messelink HA, et al. Preliminary study of the Southampton Hand Assessment Procedure for children and its reliability. *BMC Musculoskelet Disord.* 2014;15:199.